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# Sensory and analytical characteristics of a novel hybrid muskmelon fruit intended for the fresh-cut industry

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ABSTRACT

A novel hybrid muskmelon has been bred specifically for use by the fresh-cut industry in winter. Quality characteristics of fresh-cut pieces from the hybrid were compared to those of its inbred parental lines and to those of a commercial netted muskmelon (cantaloupe) and a non-netted muskmelon (honeydew) fruit available in winter. Pieces from hybrid and female line fruit had higher soluble solids content (SSC) and firmness, and lower aromatic volatile concentrations compared to those from the male line fruit. Pieces from hybrid fruit also had higher SSC (>3%) and were firmer (>5 N) than commercial fruit available during the winter, and had twice the aromatic volatile concentration of commercial honeydew and a more intense orange hue than commercial muskmelon. Consumers rated the flavor, texture, sweetness and overall eating quality of the hybrid higher than its inbred parents and winter-available honeydew and as well as or better than winter-available muskmelon. Hybrid fruit stored 5 weeks at 1 °C under modified atmospheric conditions, then fresh-cut and stored 14 d in air at 5 °C maintained good quality (firmness = 51 N, SSC > 12%, β-carotene and ascorbic acid concentrations = 18 and 182 mg $kg^{-1}$, respectively), and showed no signs of tissue translucency or surface pitting despite microbial populations >11 $\log_{10}$ $kg^{-1}$. The results indicate that the novel hybrid muskmelon is a promising new melon type for fresh-cut processing and marketing, at least during the winter season.

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## 1. Introduction

Fresh-cut fruit is a rapidly growing segment of the produce industry and is expected to exceed U.S. $1 billion by 2008 (Clement, 2004). Orange-fleshed muskmelon (*Cucumis melo* L., Reticulatus Group) and green-fleshed honeydew (*C. melo* L., Inodorus Group) (hereafter referred to as muskmelon and green honeydew, respectively) melon pieces are common components of fresh-cut fruit products and are available year-round throughout the United States.

Currently, in the United States, sweet melon fruits, as a group, are the most purchased fresh fruit (USDA, 2008a,b). The domestic U.S. melon industry, however, cannot provide the necessary product volume to fulfill this demand especially during the winter season. As a result, melons obtained from local growers and other areas within the United States during the summer months are imported from Central America during the winter season. To accommodate different transit times, fruit from the United States and Central America may be of different varieties and harvested at different maturity stages. These differences affect the quality, physiology and shelf stability of processed fresh-cut melon products (Bai et al., 2003; Beaulieu and Lea, 2007; Beaulieu et al., 2004). Melon imports to the United States from central and south America have generally been limited by (1) the relatively short shelf-life of major commercial varieties, (2) the unacceptably long (>2 weeks) surface transit times and (3) the formidable expense of air shipment. Since surface transit times from southern hemisphere production areas to the United States can take up to 5 weeks, production of a melon fruit with typical muskmelon characteristics combined with a relatively long shelf-life is required for overseas surface shipments. Also, since commercial cultivars have only a 2–3-week shelf-life depending on cultivar and harvesting stage (Kader, 1992), many breeding efforts in the United States actively seek germplasm world-wide that produce fruit that can be stored for 4–5 weeks and that have or can be bred with a flavorful muskmelon cultivar to have fruit with flavor, texture and color characteristics suitable for fresh cutting (Paul Chung, melon breeder, personal communication).

Recently, whole fruit of a novel hybrid melon, a cross between an extra firm female and a commercial muskmelon cultivar type male, was shown to have a suitably low senescence rate, suitable for

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surface shipments of up to 5 weeks. The hybrid fruit also had a sweeter, more intensely orange hue and higher phytonutrient contents than its male parent (Lester and Saftner, 2008). This hybrid fruit, unlike its male parent, is rich in ascorbic acid and β-carotene (Lester and Saftner, 2008) both of which are considered to be critically low in the current American diet (USDA, 2005). These differences should make these hybrid fruit highly suitable for fresh-cut processing especially during the winter season in the United States when melon quality and human-health compounds may be compromised to maintain suitable shelf stability for surface shipping from Latin American countries.

In this study, we compared the sensory and instrumental quality characteristics of fresh-cut pieces from a novel hybrid muskmelon intended for the fresh-cut industry to those of its inbred parents and to those of commercial muskmelon and green honeydew fruit available during the winter. The overall objective of this study was to determine the suitability of the hybrid melon for fresh-cut processing especially during the winter season.

## 2. Materials and methods

### 2.1. Plant material

Extra-firm netted melon genotype female and commercial netted-muskmelon cultivar genotype male parental lines and F1 hybrid fruit were supplied by Seminis Vegetable Seeds Inc., Oxnard, CA: hybrid fruit also were supplied by Sandstone Marketing, Yuma, AZ. Fruit were commercially grown in the same field at the Seminis research station in Woodland, CA in the summer of 2005 and 2006 and at a Sandstone Marketing commercial field in Yuma, AZ in the fall of 2005; harvested at equal ripeness (3/4-slip for male parental line, cut for hybrid and female parental line) in August and November, respectively, chilled to 4 °C and shipped in insulated containers overnight to the ARS Beltsville Agricultural Research Center, Beltsville, MD. Whole fruit free of defects were randomized into lots of either 8 (hybrid and male parental line) or 16 (female parental line) fruit for storage. Each lot of fruit was placed in a commercial cardboard shipping box lined with a plastic StePak storage bag (StePak Corp., Encinetas, CA, USA) sealed with a twist tie. A modified atmosphere of >13 kPa $O_2$ and <8 kPa $CO_2$ was passively established within all bags during 3 or 5 weeks storage at 1 °C. The RH inside the bags was ~90%.

At 0, 3 and 5 weeks after each harvest, 15–30 fruit from each genotype were surface sanitized by dipping for 5 min in a 200 μL $L^{-1}$ sodium hypochlorite (NaOCl) solution adjusted to pH 6 using 5 mol $L^{-1}$ HCl, blotted with a paper towel and processed at 5 °C using equipment cleaned with 70% (v/v) ethanol. For each genotypes, the melons were separated into 3 groups (replicates) of 5 (hybrid and male parental line) or 10 (female parental line) fruit and each fruit was uniformly peeled with a Muro CP-44 Melon Peeler (Tokyo, Japan). A few fruit with palely colored flesh were discarded as were the blossom- and stem-ends of all other fruit. Each fruit was sliced once longitudinally with a sharp knife, seeds and placental tissue were removed and ~2.5 cm latitudinal slices were prepared using a 0.2 mm-thick stainless steel strap (Ace Co., Boise, ID, USA) held taut in a hacksaw. The strap slicer was also used to prepare 2–3 cm wide pieces in trapezoidal shaped wedges from the melon slices. Preliminary experiments indicated that strap slicing produced a fresh-cut product essentially identical to that from commercial melon-cutting equipment. After pieces from each replicate were randomized, samples were removed for instrumental and microbial analyses (see below). Replicate samples were placed in 1-L lidded plastic containers (number of containers varied depending on replicate size), each container was sealed with parafilm and the containers vented through a 4 mm-diameter hole sealed with a syringe-type, 0.2-μm membrane filter. Previous experiments indicated that the $O_2$ and $CO_2$ concentrations within the containers remained at or near ambient air levels. Samples were stored 0–17 d at 5 °C.

Additional muskmelon and green-fleshed honeydew melons (unknown cultivars) were purchased from a Maryland Wholesale Market from August through December 2005 and stored overnight in air at 5 °C. For each genotype, fruit were fresh-cut processed (along with lots of hybrid fruit stored 5 weeks at 1 °C in StePak bags) into three 5-fruit replicate samples and stored for 2 d in air at 5 °C as already described.

### 2.2. Sensory analyses

In 2005 and 2006, untrained consumer preference tests were conducted, using volunteer panelists with a stated preference for muskmelons, and with no prior knowledge of the objectives of the current research project. Each panelist evaluated fresh-cut pieces from hybrid and its parental line fruit or hybrid, muskmelon and green-fleshed honeydew genotypes available during the winter season. Fresh-cut melon pieces were prepared as described above and stored for 2 d at 5 °C under aerobic conditions, followed by 2 h at 23 °C to enhance perception of aroma and taste characteristics. Sensory terminology and descriptive labels for the ends of the hedonic scales for each sensory quality characteristic evaluated were selected by the authors during a preliminary discussion panel with experienced sensory panelists. Pieces from each genotype were evaluated by 60 consumers per experiment. The sequence of sample presentation to panelists was randomized among sessions to minimize flavor carry-over effects, using the same sequence for 10 panelists within a panel session. One replicate of each hybrid and parental line fruit was evaluated across two panel sessions. Samples (two pieces) were presented one at a time in individual booths under moderate incandescent lighting. Panelists were instructed to clean their palates with a bite of low-salt saltine cracker, a sip of room temperature water and a small time lag before each sample. The panelists rated texture (mushy to firm), sweetness (none to very sweet) and melon-like flavor (none to very strong) and acceptability of appearance, texture, flavor and overall eating quality (bad to good) on unstructured 15-cm line scales, converted to scores of 0–100. Comments from panelists were solicited on the ballots. Panelists were asked to indicate gender and age in decades. On-screen ballots were prepared and data was collected using Compusense Five (Version 4.2; Compusense Inc., Guelph, Ontario, Canada).

### 2.3. Instrumental analyses

Respiration and ethylene production rates of melon pieces (150 g) from each replicate of each genotype were monitored every 6 h during a 14-d period at 5 °C after fresh-cut processing (Saftner et al., 2006). Humidified 0.2 μm-filtered air was passed through sealed jars containing the melon pieces. Carbon dioxide and ethylene contents of the outlet streams were each passed through a Porapak Q stainless steel column (2.4 m × 3.2 mm; Agilent Technologies, Rockville, MD, USA) at 60 °C and monitored using a $CO_2$ analyzer (Model CD-3A; Ametek, Pittsburgh, PA, USA) and a gas chromatograph (GC, Model 5890a Series II; Agilent Technologies, Rockville, MD, USA) equipped with a flame ionization detector (FID).

Flesh color, texture, soluble solids content (SSC), ascorbic acid, β-carotene and aromatic volatile concentrations of fruit pieces or juice extracts were generally measured at the time of cutting, and at 2, 4 or 5, 7 or 8, 10 or 11 and 14 or 17 d thereafter. Surface color (CIE $L^*$, $a^*$, $b^*$) was measured on a latitudinal cut using a Minolta chroma meter (Model CR-300, Tokyo, Japan) calibrated

with a manufacturer-supplied white calibration plate. One $L^*$, $a^*$ and $b^*$ reading was taken from each of 10 melon pieces of each replicate sample. Results are expressed as lightness ($L^*$), chroma ($C^* = [(a^*)^2 + (b^*)^2]^{0.5}$) and hue angle ($h_{ab} = \tan^{-1}[(b^*)(a^*)^{-1}]$).

The firmness of mesocarp tissue was determined using a texture analyzer (Model TA.XT*Plus*; Stable Microsystems, Gomalming, Surrey, GB). Puncture firmness was measured with a 10-mm diameter cylindrical probe to a deformation of 10 mm at 2.0 mm $s^{-1}$. One puncture test was performed on each of 10 pieces of each replicate sample, and the force/deformation curves were analyzed for peak force, area under the curve and gradient (slope) of the initial portion of the curve. For each replicate sample, SSC and the aromatic volatile concentration were determined on cheesecloth-filtered, garlic press-expressed juice from the pieces used for texture measurements. SSC was measured using a digital, temperature-compensated refractometer (model PR-101, Atago Co., Tokyo, Japan). For volatile analyses, 1 mL of juice from each replicate sample was transferred to a 4-mL vial, capped with a teflon-lined septum and stored for up to a month at −20 °C before analysis. Analysis of aromatic volatile concentration using a solid-phase microextraction (SPME, Suppelco Co., Bellefonte, PA, USA) technique and gas chromatography was performed as previously described (Saftner, 1999) except that the SPME fiber used for volatile collection was coated with 75 μm carboxen-polydimethylsiloxane. Constructing calibration curves for each volatile analyte in each melon sample is not feasible and thus total volatile concentration is reported in flame ionization (FID) area response units of picoamps (pA) rather than absolute amounts of individual analytes (Saftner et al., 2002).

For vitamin assays, free ascorbic acid and dehydroascorbate were extracted from 7.5-g frozen (−80 °C) tissue puree from each replicate sample and reported as total ascorbic acid (Hodges et al., 2001). β-Carotene was extracted under low light conditions from 20-mg samples of lyophilized tissue puree (Lester et al., 2005). Both vitamins are reported in units of g $kg^{-1}$ fresh weight. β-Carotene levels are calculated using fresh weight/dry weight ratios.

### 2.4. Microbial analysis

For each replicate melon sample, two fresh-cut pieces (~35 g) were placed in a filter-lined stomacher bag, a 1:3 dilution of sample was prepared with phosphate-buffered saline (PBS at 100 mmol $L^{-1}$, pH 7.0), the pieces were coarsely crushed with a rubber mallet and the resulting extract pummeled in a Stomacher blender (model Stomacher 80, Steward Medical, London, UK) for 2 min at normal speed. The resultant slurry was filtered, serially diluted with PBS as necessary to ensure countable concentrations and 1-mL aliquots were plated in duplicate onto aerobic count and yeast and mold count plates (Petrifilm™, 3M Microbiology, St. Paul, MN, USA). The inoculated aerobic count plates were incubated aerobically at 35 °C and >90% RH for 48 ± 3 h, and the yeast and mold count plates were stored aerobically at 23 °C and >90% RH for 5 d. After incubation, the aerobic count plates were read using a 3M Petrifilm™ Plate Reader and yeast and mold count plates were read manually. Counts are reported as $\log_{10}$ CFU $kg^{-1}$.

### 2.5. Statistical analysis

Data were analyzed using SigmaStat (Version 3.0; SPSS Inc., Chicago, IL, USA) and PROC MIXED (SAS Version 9.13, SAS Institute Inc., Cary, NC, USA). The experimental design was a randomized complete block with three replications. For instrumental data, sources of variation were genotype (3), replicates (3) and storage duration [4 (August, 2005 harvest) or 5 (November, 2005 and August, 2006 harvests)]. For sensory data, sources of variation were genotype (3) and replications (3), both considered fixed effects, and panel sessions (6) and panelists (60) considered random effects. Treatment means were tested using Tukey's HSD, $\alpha = 0.05$. For sensory–sensory and instrument–sensory comparisons, raw data were used to calculate Pearson correlation coefficients which were used to model the relationships (SAS Version 9.13, SAS Institute Inc.): (*), (**) and (***) in the text indicate 0.05, 0.01 and 0.001 levels of significance, respectively. Sensory data were additionally examined by Factor Analysis (FA) using the Promax (Oblique) Rotation Method via SAS Proc FACTOR to extract three factors. The FA "re-partitions" the sensory–sensory correlation matrix to extract factors that describe variability shared in common among the sensory descriptors. The oblique rotation method allows the variability represented by these extracted factors to be correlated with one another, just as many of the sensory descriptors are correlated with one another. Unless stated otherwise, only results significant at $\alpha \leq 0.05$ are discussed.

## 3. Results and discussion

### 3.1. Respiration and ethylene production rates and microbial analyses

In 2005 (Fig. 1) and 2006 (data not shown), the mean respiration rates (measured as $CO_2$ evolution rates) of freshly prepared melon pieces from hybrid fruit were ~20% higher than those from female line fruit and ~15% lower than those from male line fruit. Respiration rates remained stable during the initial 7–8 d of storage, and were in the same range as those of other fresh-cut muskmelon and honeydew pieces (Beaulieu and Gorny, 2004; Saftner et al., 2006) stored in air at 5 °C. After day 8, the respiration rate of all genotypes increased rapidly and coincided with a gross contamination of the melon piece surfaces with aerobic microbes (Fig. 2), which were mostly bacteria since yeasts and molds were not detected until the last day of storage and did not contribute much to the overall aerobic count. During the period of increased respiration, the microbial populations increased from 7–8 $\log_{10}$ $kg^{-1}$ to >11 $\log_{10}$ $kg^{-1}$, depending on fruit line, and probably contributed, at least in part, to the increasing respiration rates. Increased respiration rates of melon pieces during storage are associated with microbial contamination (Portela and Cantwell, 2001; Saftner et al., 2006).

Netted muskmelon (cantaloupe) fruit generally have higher respiration rates, mature earlier and have less shelf stability than non-netted muskmelons (honeydews) (Kader, 1992) or other low respiring melon fruit such as the hybrid and female line genotypes. Respiration rates of freshly prepared melon pieces from hybrid and parental line fruit were 10–24% lower when processed from fruit

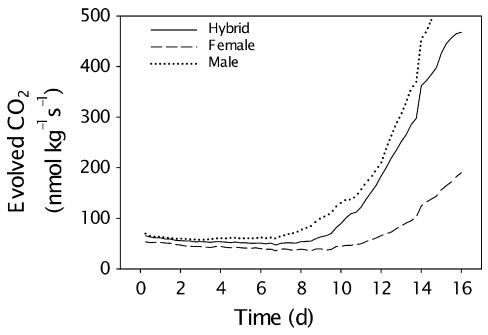


**Fig. 1.** Respiration rate, as evolved $CO_2$, of fresh-cut melon pieces from commercially grown netted hybrid and its parental lines (female = extra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) harvested in August, 2005.

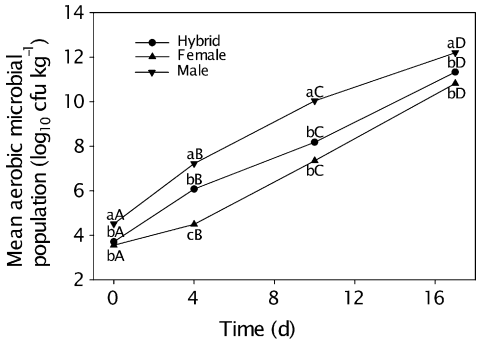


**Fig. 2.** Aerobic microbial counts of fresh-cut melon pieces prepared from commercially grown netted hybrid and its parental lines (female = extra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) harvested in August, 2005 and stored up to 17 d in air at 5 °C. Within time periods, symbols labeled with the same lowercase (a–c) letters are not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 3$). Within genotypes, symbols labeled with the same uppercase (A–D) letters are not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 3$).

stored 5 weeks vs. 3 weeks (data not shown) and was probably an indication that whole fruit of all genotypes were slowly senescing during storage.

The ethylene production rate of freshly cut melon pieces from male line fruit was ~80 pmol $kg^{-1}$ $s^{-1}$ and decreased to undetectable (<5 pmol $kg^{-1}$ $s^{-1}$) concentrations by day 7. Ethylene production rate in freshly cut melon pieces from hybrid fruit was <30 pmol $kg^{-1}$ $s^{-1}$ and decreased to undetectable concentrations by day 3. Ethylene was not detected in freshly cut pieces from female line fruit. Ethylene production rates have previously been shown to decrease in muskmelon (Portela and Cantwell, 2001; Saftner et al., 2006) and honeydew (Saftner et al., 2006) pieces during storage. The relatively high initial respiration and ethylene production rates in pieces from male line fruit may be indicative of a fast ripening-fast senescing genotype and/or one highly prone to wound respiration and ethylene production.

### 3.2. Instrumental quality analyses of fresh-cut pieces from hybrid and parental line fruit

During storage of whole August 2005-harvested fruit, internal flesh firmness declined the most in male parental line fruit regardless of which firmness measurement parameter was chosen (Table 1). Although $F_{max}$ is the measurement parameter most often reported in horticultural firmness studies, the area under the curve seems to be a better parameter since it better approximates the energy required to penetrate the tissue. There are also arguments to be made for choosing slope of the initial portion of the force/deformation curve, which engineers relate to stiffness. In an earlier whole-fruit study with other lots of hybrid and parental line fruit, internal flesh firmness, measured as $F_{max}$, also declined the most in whole male parental line fruit, but the decline was not always significantly different from the decline in the internal firmness of whole hybrid fruit (Lester and Saftner, 2008).

Freshly cut pieces from hybrid line fruit stored 0, 3 or 5 weeks were always firmer than those from male line fruit and softer than those from female line fruit regardless of which firmness measurement parameter was chosen (Table 1). The large differences in firmness among fruit lines persisted throughout storage of the fresh-cut pieces and, regardless of the firmness parameter chosen, firmness always declined in each fruit line during storage, although not always significantly. Generally, pieces from female line fruit softened the least during storage, followed by melon pieces from hybrid and male line fruit. Firmness decline during storage of the fresh-cut pieces was less pronounced the longer the whole fruit were stored before fresh-cut processing. Hybrid fruit stored 5 weeks, then fresh-cut and stored for 14 d in air at 5 °C maintained good firmness, i.e., firmness within the range of those reported for freshly harvested netted (Beaulieu and Lea, 2007) and non-netted (Miccolis and Saltveit, 1991) melons. Freshly cut pieces from November, 2005- and August 2006-harvested hybrid and parental line fruit showed similar patterns of softening during storage as those shown in Table 1 for August 2005-harvested fruit (data not shown).

Another important marketable (consumer acceptance) quality attribute is melon flesh color. Melon flesh color is a measure of lightness ($L^*$; black = −100 and white = +100), chroma ($C^*$; color intensity) and hue angle ($h_{ab}$; color purity). The flesh color of pieces from hybrid and parental line fruit was stable throughout stor-

**Table 1**
Mean instrumental firmness values for fruit pieces from a commercially grown netted hybrid muskmelon and those of its parental lines (female = extra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) harvested in August, 2005

| Fruit storage/ genotype | Melon piece storage duration (d) | Firmness | | |
|---|---|---|---|---|
| | | $F_{max}$ (N) | Area (mJ) | Gradient (kN $m^{-1}$) |
| 0 week | | | | |
| Hybrid | 0 | 59.0 b A | 217.1 b A | 38.2 b A |
| Female | 0 | 97.1 a A | 344.6 a A | 52.8 a A |
| Male | 0 | 15.9 c A | 60.2 c A | 15.6 c A |
| Hybrid | 14 | 43.8 b B | 151.9 b B | 22.2 b B |
| Female | 14 | 81.6 a B | 269.6 a B | 33.9 a B |
| Male | 14 | 8.8 c B | 30.0 c B | 7.9 c B |
| 3 weeks | | | | |
| Hybrid | 0 | 39.2 b A | 150.3 b A | 26.3 b A |
| Female | 0 | 96.5 a A | 340.1 a A | 47.7 a A |
| Male | 0 | 12.5 c B | 47.2 c A | 10.8 c A |
| Hybrid | 4 | 41.5 b A | 147.3 b A | 22.0 b B |
| Female | 4 | 91.4 a AB | 308.9 a B | 40.2 a B |
| Male | 4 | 14.1 c A | 45.7 c A | 9.4 c B |
| Hybrid | 10 | 39.1 b A | 142.0 b A | 22.4 b B |
| Female | 10 | 92.4 a AB | 307.5 a AB | 39.5 a B |
| Male | 10 | 11.8 c B | 37.5 c B | 8.9 c BC |
| Hybrid | 17 | 36.7 b A | 135.2 b A | 21.1 b B |
| Female | 17 | 87.1 a B | 280.2 a C | 32.4 a C |
| Male | 17 | 10.5 c C | 34.4 c B | 8.1 c C |
| 5 weeks | | | | |
| Hybrid | 0 | 52.5 b A | 184.7 b A | 27.1 b A |
| Female | 0 | 84.3 a A | 293.7 a A | 39.1 a A |
| Male | 0 | 10.8 c A | 40.4 c A | 8.4 c A |
| Hybrid | 5 | 50.7 b A | 175.3 b A | 24.2 b B |
| Female | 5 | 81.9 a A | 276.0 a A | 33.8 a B |
| Male | 5 | 10.7 c A | 36.7 c A | 33.8 c A |
| Hybrid | 11 | 53.0 b A | 174.1 b A | 22.6 b B |
| Female | 11 | 85.5 a A | 280.3 a A | 33.3 a B |
| Male | 11 | 10.3 c A | 33.4 c A | 7.6 c A |
| Hybrid | 14 | 51.5 b A | 172.3 b A | 22.3 b B |
| Female | 14 | 87.2 a A | 282.0 a A | 31.8 a B |
| Male | 14 | 9.7 c A | 31.7 c A | 7.5 c A |

Whole fruit were stored 0, 3 or 5 weeks at 1 °C in a modified atmosphere followed by fresh-cut processing and storage of the fresh-cut melon pieces at 5 °C in air for 0–17 d. Lowercase letters within a column indicate significant differences ($\alpha = 0.05$, $n = 3$, Tukey's HSD) among fruit lines within a fresh-cut storage period. Uppercase letters within a column indicate significant differences ($\alpha = 0.05$, $n = 3$, Tukey's HSD) over the fresh-cut storage period of a genotype within a whole fruit storage period. The area under the force/deformation curve approximates the energy required to penetrate the tissue while the gradient of the initial portion of the curve relates to tissue stiffness.

**Table 2**
Comparison of melon pieces from commercially grown netted hybrid and its parental lines (female = extra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) harvested in August, 2005 and 2006 for soluble solids content, aromatic volatile concentration, surface color, total ascorbic acid and β-carotene

| Genotypes | SSC (%) | Volatile conc. (pA) | Surface color | | | Ascorbic acid (mg kg$^{-1}$) | β-Carotene (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | $L^*$ | $C^*$ | $h_{ab}$ | | |
| Hybrid | 12.1 a | 464 b | 66.05 b | 37.52 b | 71.61 b | 182 a | 17.8 a |
| Female | 9.9 b | 112 c | 67.31 a | 39.00 a | 71.57 b | 179 a | 18.6 a |
| Male | 8.5 c | 3224 a | 67.67 a | 34.74 c | 73.13 a | 169 a | 16.9 a |

Whole melons were stored 3 or 5 weeks at 1 °C in a modified atmosphere followed by fresh-cut processing and storage of the fresh-cut melon pieces at 5 °C in air for 0, 4–5, 10–11 and 14–17 d. Total volatile concentration collected by headspace SPME is reported in FID area response units of picoamps (pA). Corresponding instrumental data of fresh-cut melon pieces from each genotype were combined. SSC = soluble solids content. Means within a column followed by the same letter were not significantly different, Tukey's HSD, $\alpha = 0.05$, $n = 24$ for SSC, volatile concentration, total ascorbic acid and β-carotene; $n = 240$ for surface color.

age (data not shown) and thus color data for all storage periods from August-harvested 2005 and 2006 fruit were combined. Pieces from female line and hybrid fruit had a lower $h_{ab}$, more red than yellow hue, i.e., more orange-colored, than pieces from male line fruit (Table 2). The orange color also was noticeably more intense (higher Chroma) in pieces of female and hybrid line fruit than in pieces of male line fruit. Pieces from parental line fruit had a slightly higher $L^*$ than pieces from hybrid fruit, but this variation between parental and hybrid pieces was not apparent by the authors' visual examination of the pieces.

Sweetness (sugar content) and aroma are also considered to be important quality characteristics in fresh melons (Shalit et al., 2001). Sugars in melon fruit can be determined indirectly as SSC and aroma measured as total aromatic volatile concentration. While SSC and aromatic volatile concentrations in pieces from hybrid and parental line fruit decreased slowly during storage, the changes were never significant and thus all SSC and volatile data for all melon piece storage periods for August-harvested 2005 and 2006 fruit were combined. Juice extracts of pieces from hybrid fruit had the highest SSC, followed by those from female line fruit, which in turn had a higher SSC than those from male line fruit (Table 2). In contrast, the total evolved volatile concentration from juice extracts of pieces from male line fruit was 7 and 29 times higher than that from juice extracts of hybrid and female line fruit, respectively (Table 2). The measured differences in SSC and aromatic volatile concentrations among genotypes have been previously reported to affect the sweetness (Lester and Shellie, 1992) and aroma (Beaulieu and Lancaster, 2007; Saftner et al., 2006) of fresh melon products. Our SSC results also are consistent with the finding of Beaulieu et al. (2003) that commercial muskmelon fruit have higher total sugar concentrations than parental line fruit, an indication of hybrid vigor. Likewise, the pattern of total volatile concentration being highest in male parental line fruit followed by hybrid and female parental line fruit is consistent with the finding of Beaulieu and Lea (2003) that total ester concentrations follow the same pattern in fresh-cut pieces of commercial orange-fleshed cantaloupes and their parental lines.

In addition to the superior quality characteristics already described, ascorbic acid and β-carotene concentrations remained stable in hybrid and parental line fruit both prior to processing (Lester and Saftner, 2008) and afterwards during storage as fresh-cut pieces (data not shown). As such, ascorbic acid and β-carotene concentrations for all melon piece storage periods for corresponding August-harvested 2005 and 2006 fruit were combined and shown as such in Table 2, The pooled data indicated that pieces from hybrid and female line fruit had slightly higher phytonutrient contents (ascorbic acid, β-carotene), albeit not significantly, than pieces from male line fruit (Table 2). The ascorbic acid and β-carotene concentrations of pieces from hybrid and parental line fruit were in the same range as the USDA Standard Reference for muskmelon ascorbic acid and β-carotene concentrations (USDA, 2007). In our earlier whole fruit storage study, we reported that both hybrid and female line fruit had significantly higher ascorbic acid and female line fruit significantly higher β-carotene concentrations than male line fruit (Lester and Saftner, 2008). Taken together, our results indicate that hybrid fruit stored up to 5 weeks, then fresh-cut and stored as pieces in air at 5 °C for up to 17 d either meet or exceed the USDA Standard Reference for muskmelon ascorbic acid and β-carotene concentrations.

### 3.3. Sensory analysis of fresh-cut pieces from hybrid and parental line fruit

Consumers distinctly preferred the overall eating quality of melon pieces from hybrid fruit compared to those from male and female line fruit (Table 3). Pieces from hybrid fruit scored highest, albeit not always significantly, for intensity of sweetness and melon-like flavor and for the acceptability of appearance, texture and flavor. The numerical differences in sensory quality characteristics between pieces from hybrid and parental line fruit were sometimes large and likely to be of practical importance. Pieces from female line fruit had the highest textural intensity and lowest textural acceptability scores with many consumers indicating that pieces from female line fruit were *too hard* or *too tough*. The textural intensity of pieces from hybrid fruit also scored high (Table 3) but only four (~3%) consumers made comments to the effect that firmness was too high.

A long-term goal of our research is to better understand the relationships among sensory quality characteristics of fresh-cut

**Table 3**
Sensory characteristics of fresh-cut melon pieces from commercially grown netted hybrid and its parental lines (female = extra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) harvested in August 2005 and 2006

| Genotype | Sensory characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Appearance | Textural intensity | Textural acceptability | Sweetness intensity | Flavor intensity | Flavor acceptability | Overall eating quality |
| Hybrid | 82.7 a | 73.6 b | 65.8 a | 58.5 a | 55.2 a | 60.2 a | 64.1 a |
| Female | 77.3 b | 88.4 a | 39.1 c | 38.0 c | 35.4 b | 35.0 b | 31.9 c |
| Male | 76.3 b | 28.4 c | 53.6 b | 52.1 b | 55.4 a | 57.2 a | 50.8 b |

Whole fruit were stored 3 weeks at 1 °C in a modified atmosphere, cut into fresh-cut pieces, and the pieces stored 2 d at 5 °C under aerobic conditions and 2 h at 23 °C. Means within a column followed by the same letter (a–c) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 240$).

**Table 4**
Sensory characteristics scored for fresh-cut melon pieces from commercially grown netted hybrid, orange-fleshed muskmelon and green-fleshed honeydew cultivars/genotypes in December, 2005

| Genotype | Sensory characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Appearance | Textural intensity | Textural acceptability | Sweetness intensity | Flavor intensity | Flavor acceptability | Overall eating quality |
| Hybrid | 74.1 a | 70.3 a | 63.6 a | 56.3 a | 50.5 a | 53.1 a | 53.8 a |
| Muskmelon | 71.4 a | 55.3 b | 61.4 a | 48.6 b | 48.0 a | 36.7 b | 50.1 a |
| Honeydew | 59.0 b | 58.8 b | 52.8 b | 37.8 c | 34.7 b | 49.9 a | 35.5 b |

Whole hybrid fruit were stored 5 weeks at 1 °C in a modified atmosphere, cut into fresh-cut pieces, and the pieces stored 2 d at 5 °C under aerobic conditions and 2 h at 23 °C. Whole muskmelon and honeydew fruit were purchased from a wholesale market in December, 2005, fresh-cut processed and stored in the same way as hybrid fruit. Means within a column followed by the same letter (a–c) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 120$).

melons, with the purpose of more accurately accessing the impact of sensory quality characteristics on eating quality. For the three genotypes used in this study, overall eating quality was most highly correlated with flavor acceptability ($r = 0.88^{***}$). Eating quality was also highly correlated with sensory scores for textural acceptability ($r = 0.79^{***}$), sweetness intensity ($r = 0.75^{***}$) and melon-like flavor intensity ($r = 0.73^{***}$). Sweetness intensity was correlated to flavor intensity ($r = 0.79^{***}$) and flavor acceptability ($r = 0.80^{***}$). These results suggest that flavor-related characteristics best predict consumer preferences for overall eating quality, though textural quality also contributes.

### 3.4. Comparison of melon pieces from hybrid fruit to those from netted and non-netted muskmelon fruit available during the winter

The instrumental and sensory quality characteristics of melon pieces from hybrid fruit stored 5 weeks prior to fresh-cut processing were compared to commercially grown muskmelon and green honeydews available during the winter. Consumers distinctly preferred the overall eating quality of melon pieces from hybrid and winter-available netted muskmelon fruit to those from winter-available non-netted muskmelon fruit (Table 4). Pieces from hybrid fruit scored highest, though not always significantly, for intensity of texture, sweetness and melon-like flavor and for acceptability of texture and flavor. Differences in sensory characteristics among genotypes were sometimes large (>10) and would likely be of practical importance.

Instrumental measurements performed at the time of sensory analyses showed that pieces from hybrid fruit had >4% higher SSC compared to those from winter-available melons (Table 5). This difference is probably of practical importance since consumers scored pieces from hybrid fruit sweeter than those from the winter-available melons (Table 4). Hybrid fruit also had more than double the aromatic volatile concentration than winter-available honeydew fruit but less than a third of the volatile concentration of winter-available muskmelon fruit (Table 5). Pieces from hybrid and netted muskmelon had the same melon-like flavor intensity despite their large difference in aromatic volatile concentration.

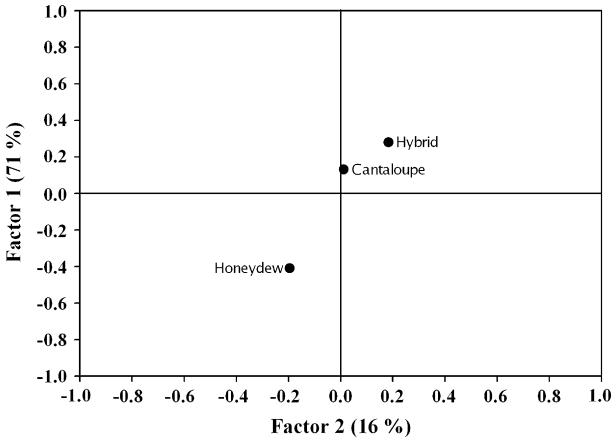


**Fig. 3.** Factor Analysis of sensory data for fresh-cut pieces from netted hybrid (November 2005-harvested) and winter-available muskmelon and honeydew fruit. Flavor, sweetness and overall eating scores were associated with Factor 1 and texture scores loaded onto Factor 2.

Pieces from hybrid fruit had an higher puncture firmness ($F_{max}$) than those from winter-available melons (Table 5), and consumers correspondingly scored pieces from hybrid fruit highest in textural intensity and acceptability (Table 4). Lightness and $h_{ab}$ was lowest and $C^*$ highest in hybrid fruit pieces (Table 5), giving the tissue a clear, intense typical melon orange hue that consumers found highly acceptable in appearance (Table 4).

Factor Analysis was conducted on the sensory data to identify variability shared in common among the sensory descriptors (i.e., factors) for the three genotypes examined. The Promax Rotation Method was applied to the extracted factors to identify and estimate any correlation among the extracted factors. Fresh-cut pieces from hybrid fruit that had the highest scores for flavor quality characteristics also had the highest positive score for Factor 1 (explaining 71% of the variation observed among the sensory descriptors), with high loading values for melon-like flavor intensity and flavor acceptability, sweetness and overall eating quality (Fig. 3). Likewise, pieces from winter-available honeydews that had

**Table 5**
Mean instrumental values on the day of sensory evaluation for melon pieces from commercially grown netted hybrid, muskmelon and green-fleshed honeydew cultivars/genotypes in December, 2005

| Genotypes | SSC (%) | Volatile concentration (pA) | Firmness (N) | Surface color | | |
|---|---|---|---|---|---|---|
| | | | | $L^*$ | $C^*$ | $h_{ab}$ |
| Hybrid | 12.2 a | 346 b | 46.9 a | 67.2 c | 36.2 a | 75.7 c |
| Muskmelon | 7.9 b | 1031 a | 34.7 c | 70.9 a | 32.6 b | 78.0 b |
| Honeydew | 7.3 b | 168 c | 41.8 b | 70.0 b | 23.5 c | 115.7 a |

Whole hybrid fruit were stored 5 weeks at 1 °C in a modified atmosphere, cut into fresh-cut pieces, and the pieces were stored for 2 d at 5 °C under aerobic conditions and 2 h at 23 °C. Whole muskmelon and honeydew fruit were purchased from a wholesale market, fresh-cut processed and the fresh-cut pieces stored the same way as those from hybrid fruit. Total volatile concentration collected by headspace SPME is reported in FID area response units of picoamps (pA). SSC = soluble solids content. Means within a column followed by the same letter (a–c) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 24$ for SSC, volatile concentration and firmness and $n = 240$ for surface color).

generally low scores for flavor quality had a negative score on Factor 1. Factor 2 explained 16% of the variation observed among the sensory descriptors and intensity and acceptability of texture loaded onto this factor. Genotypes that scored generally high for intensity and/or acceptability of texture had positive scores for Factor 2 and the honeydew genotype which scored lowest in these sensory quality characteristics had a negative score for Factor 2. Just as the sensory descriptors loading onto Factor 1 and Factor 2 are correlated with one another, the oblique rotation of the factors estimates a correlation between Factor 1 and Factor 2 of 0.32. In summary, Factor Analysis indicated that hybrid and winter-available muskmelon genotypes had higher sensory quality than the winter-available honeydew genotype with the hybrid having the best sensory quality. Results from Factor Analysis were similar to other statistical analyses of the sensory data as described above.

## 4. Conclusions

The relatively long shelf stability of hybrid fruit and its fresh-cut product makes it suitable for overseas surface shipments to supply the fresh-cut industry during lags in U.S. production. Consumers preferred the flavor, sweetness, texture and overall eating quality of fresh-cut pieces from hybrid fruit to those of at least some winter-available honeydews and as well as or better than pieces of at least some winter-available muskmelons. Hybrid fruit stored up to 5 weeks at 1 °C under a modified atmosphere, then fresh-cut and the fresh-cut product stored 14 d at 5 °C in air maintained good quality, i.e., with firmness, color, SSC and phytonutrient contents as good as or better than freshly processed muskmelons, at least those available during the winter. The aromatic volatile concentration of hybrid fruit was less than a third of that present in muskmelon fruit, but consumers still scored hybrid and muskmelon fruit equally well for intensity of melon-like flavor and hybrid fruit superior for flavor acceptability. The results further indicate that the novel netted hybrid melon is a promising new melon type for fresh-cut processing and marketing, at least during the winter season.

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